(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
20 December 2001 (20.12.2001)

PCT

(10) International Publication Number
WO 01/96853 A1

(51) International Patent Classification[7]: G01N 29/00, 29/04, 29/06 // G01B 17/08, G01S 15/02

(21) International Application Number: PCT/SE01/01007

(22) International Filing Date: 9 May 2001 (09.05.2001)

(25) Filing Language: Swedish

(26) Publication Language: English

(30) Priority Data:
0002243-4 16 June 2000 (16.06.2000) SE

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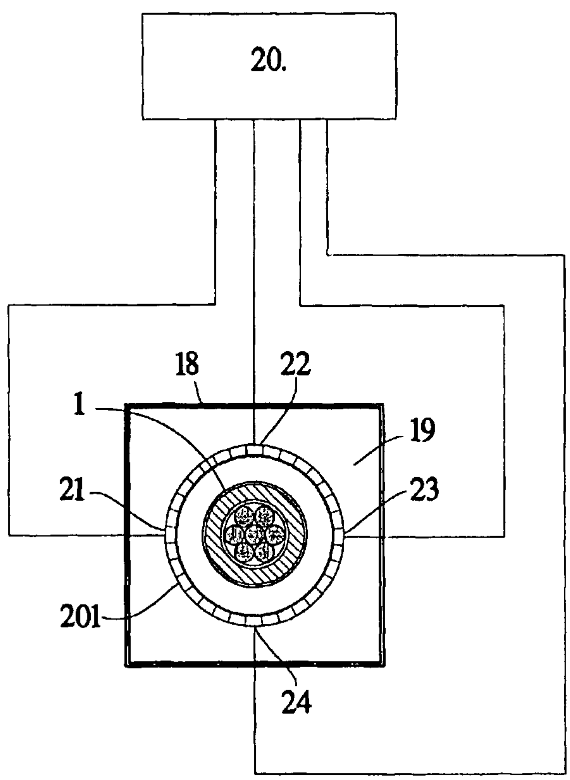
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AT (utility model), AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, CZ (utility model), DE, DE (utility model), DK, DK (utility model), DM, DZ, EC, EE, EE (utility model), ES, FI, FI (utility model), GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SK (utility model), SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian

[Continued on next page]

(54) **Title:** A METHOD OF MEASURING TOPOGRAPHY IN AN INTERFACE AND USE OF THE METHOD FOR A HIGH-VOLTAGE CABLE



(57) **Abstract:** A method, in a high-voltage cable (1) comprising a central conductor (2) consisting of one or more strands (2a), an inner semiconductive layer (3) and a surrounding insulating layer (4), of measuring the topography (3a, 3c, 3d, 3e, 3f, 3g) at the interface between the inner semiconductive layer (3) and the insulating layer (4). A plurality of probes are used, arranged in a fixed array, spatially fixed at the outside of the cable, to emit ultrasound, with a frequency of between 0.1 MHz and 20 MHz, preferably between 0.5 MHz and 5 MHz, in the form of pulses, and to receive (detect) reflected sound (echo). The probes are activated systematically, one at a time, or a few at a time, such that the pulses are emitted from the probes cyclically with a time lag between the pulses, whereas reflected sound is detected in a plurality of, or in all of, the probes.

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patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

A method of measuring topography in an interface and use of the method for a high-voltage cable

TECHNICAL FIELD

The present invention relates to a method, in a high-voltage cable comprising a conductor, an inner semiconductive layer and an insulating layer, of measuring the topography in the interface between the inner semiconductive layer and the insulating layer.

A preferred embodiment relates to a method, in a high-voltage cable which, in addition, comprises an outer semiconductive layer, of measuring the topography in the interface between the outer semiconductive layer and the insulating layer.

BACKGROUND ART

Cables with a central conductor surrounded by one or more insulating layers have long been an important part of our public power-supply network. With a view to reducing the network of overhead lines, an increasing proportion of the distribution network has been laid underground and in that context requirements for an increasing operating voltage in the cable systems have been a driving force for a development towards both better cable designs and better material and production control.

Apparatus and methods for continuous control of cable manufacture were proposed at an early stage.

US 1,815,710 describes a method of controlling the thickness of material in a cable, especially the thickness of a metallic sheath surrounding an insulating layer. By means of induction coils, mounted in pairs and connected in a Wheatstone bridge, deviations from symmetry are indicated.

US 2,177,528 describes a method of measuring the concentricity of an insulated cable. A sensor, for example a metal roll, is moved over the outer surface of the cable and the capacitance between the conductor of the cable and the sensor is measured.

US 2,721,975 describes two sensors diametrically placed at the outer surface of the cable. The capacitance between the conductor of the cable and the sensors is included in two branches in a measuring bridge, the unbalance of which hence indicates the eccentricity of the cable.

US 3,407,352 suggests the use of two magnetic coils, mounted at different distances from an object to be measured, to monitor the thickness of an insulating layer over a conductive layer. A high-frequency voltage, for example 100 kHz, is applied to the coils and the phase difference is detected by means of a measuring bridge.

US 3,500,185 suggests the use of a pair of diametrically placed measuring probes in contact with the surface of a cable in order to measure the eccentricity of the cable and the thickness of the insulation. The probes may be turned around the cable and are connected alternately into an arm in a capacitance bridge.

In the methods described above, the composition of the cable is assumed to be considerably simpler than what is customary today. Instead of one single, hopefully homogeneous, insulating layer which surrounds a conductor, the current practice is normally to have an inner semiconductive layer around the conductor and an outer semiconductive layer outside the insulating layer. The thickness of each of these layers is significant for the function and service life of the cable. This creates quite new problems and raises new questions to be answered.

OBJECT OF THE INVENTION

The main object of the present invention is to suggest a simple and reliable method of performing quality control of high-voltage cables during continuous production.

A second object is to carry out a corresponding control of test objects on a laboratory scale.

A third object is to suggest a simplified method of measuring the topography for an interface between layers in a high-voltage cable, without the use of movable sensors.

The present invention relates particularly to measurement of the topography in the interface between an inner semiconductive layer and an insulating layer in a high-voltage cable while at the same time being designed to measure also the topography in the interface between an outer semiconductive layer and the insulating layer.

SUMMARY OF THE INVENTION

The present invention relates to a method, in a high-voltage cable comprising a conductor, an inner semiconductive layer and an insulating layer, of measuring the topography in the interface between the inner semiconductive layer and the insulating layer. A plurality of probes arranged in a fixed array, spatially fixed at the outside of the cable, are used to emit ultrasound, with a frequency of between 0.1 MHz and 20 MHz, preferably between 0.5 MHz and 5 MHz, in the form of pulses and to receive (detect) reflected sound (echo). The probes are activated systematically, one or a few at a time, such that the pulses are emitted from the probes cyclically with a time lag between the pulses, whereas reflected sound is detected in a plurality of, or in all of, the probes.

GENERAL DESCRIPTION OF THE INVENTION

The desire to achieve increased operational reliability and reduced environmental disruption in the distribution of electric power at present leads to a growing demand for high-voltage cables. At the same time, the quality requirements for high-voltage cables increase continuously.

The fundamental requirements that the cable can be produced with a very small eccentricity and without any significant ovality and that the insulation can be manufactured without impurities or blisters can nowadays be fulfilled to such an extent that other parameters are starting to be of decisive importance for the usefulness of the cable. Among these parameters, the topography in the interface between an insulating layer and an inner semiconductive layer has a prominent position.

The present invention proposes a way of contributing to an increased quality and hence reduced costs by suggesting a method for measuring the topography in the interface between an inner semiconductive layer, which surrounds a central conductor, and an insulating layer, which in turn surrounds the semiconductive layer. Outside of the insulating layer, an outer semiconductive layer is advantageously applied.

According to the invention, it is proposed to use ultrasound with a frequency of between 0.1 MHz and 20 MHz, preferably between 0.5 MHz and 5 MHz, for measuring the topography in the interface. The ultrasound is emitted in the form of pulses from a plurality of probes arranged in a fixed array, spatially fixed at the outside of the cable. The array should surround the cable. With the same probes, reflected sound (echo) is detected. The probes are activated systematically, one at a time, or a few at a time, such that the pulses are emitted from the probes

cyclically with a time lag between the pulses, whereas reflected sound is detected in a plurality of, or in all of, the probes. The systematic activation advantageously occurs in groups, whereby an intentional delay between the points in time for the activation of the respective probes within a group provides a possibility of efficiently focusing the emitted sound to a desired point (so-called phased array).

Within the scope of the invention it is also possible, by using several groups which are activated synchronously, for example two groups diametrically placed around the cable, to focus ultrasound at several points at the same time, preferably at two points, provided that this does not have a negative effect through interaction of the reflections of the two rays during the detection.

The invention particularly relates to a method, in a high-voltage cable with an outer diameter of between 10 mm and 100 mm, comprising an insulating layer of crosslinked polyethylene (PEX, XLPE), of measuring the topography in the interface between the inner semiconductive layer and the insulating layer. Other extruded insulating materials including, but not limited to, high-density polyethylene (HDPE) and ethylene-propylene rubber (EPR), also fall within the scope of the invention.

In a high-voltage cable comprising a conductor, an inner semiconductive layer, an insulating layer and an outer semiconductive layer, the topography in the interface between the outer semiconductive layer and the insulating layer may also be advantageously measured. The method is, of course, also applicable when a high-voltage cable is built up with several insulating layers or in some other way differs from the cable design described as an example in this application.

The method entails considerable advantages if the ultrasound is focussed on the respective interface between semiconductive layers and insulating layers and if the detected ultrasonic signal is amplified selectively such that signals from the respective interface is amplified more than the other signals from intermediate or outside disturbance sources.

In a preferred embodiment of the method, from the detected signals, the radial distance s between the interfaces of the outer and inner semiconductors towards the insulating layer is calculated, and the gradient of s is calculated at varying space coordinates along one of the interfaces or with a cylindrical coordinate system, adapted to the symmetry axis of the cable, at a constant radius defined, for example, for describing the expected position for one of the interfaces. When the value of the gradient of s exceeds a predetermined limit value, an alarm signal is sent and/or the cable is marked with a colour.

Further, the frequency of the ultrasound may be adapted to the outer diameter of the cable, to the diameter of the conductor, or to the thickness of the inner semiconductive layer.

Use of the method for continuous monitoring of cable manufacture, or for laboratory analysis of cables, is also within the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described in greater detail with reference to the accompanying drawings where

Figure 1 schematically shows the cross section of a high-voltage cable and ultrasonic equipment intended for the method according to the invention,

Figure 2 shows a first cross section of a high-voltage cable with a non-ideal shape of an inner semiconductive layer,

Figure 3 shows a second cross section of a high-voltage cable with a non-ideal shape of an inner semiconductive layer,

Figure 4 shows a third cross section of a high-voltage cable with a non-ideal shape of an inner semiconductive layer,

Figure 5 schematically shows a device for continuous control of a manufactured high-voltage cable.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 shows the cross section of a high-voltage cable 1, with a central conductor 2 consisting of a plurality of strands 2a. The conductor 2 is surrounded by an inner, semiconductive layer 3, an insulating layer 4, of cross-linked polymer, and an outer semiconductive layer 5. The semiconductive layers 3, 5 and the insulating layer 4 are illustrated in an ideal case with a completely circular symmetry.

At the outer surface of the high-voltage cable 1, there are schematically shown three probes 11, 12, 13 for the supply of ultrasound and detection of reflected sound from the interfaces between the insulating layer 4 and the respective semiconductive layers 3, 5. The ultrasonic probes 11, 12, 13 are interconnected by a superordinate control unit 10.

Figure 2 shows, in a corresponding way, the cross section of a high-voltage cable 1, with a central conductor 2, consisting of a plurality of strands 2a. The conductor 2 is surrounded by an inner semiconductive layer 3, of essen-

tially uniform thickness, but this layer 3 has a wavy shape formed by the strands 2a, with a pattern of valleys 3a winding their way around the conductor 2.

Figure 3 shows, in a corresponding way, the cross section of a high-voltage cable 1, with a central conductor 2, consisting of a plurality of strands 2a. The conductor 2 is surrounded by a semiconductive tape 6, with a longitudinal, overlapping joint 6b. An inner semiconductive layer 3, of essentially uniform thickness, has become thicker at the overlapping joint 6b. The thicker portion is interrupted by a steep slope 3b.

Figure 4 shows, in a corresponding way, the cross section of a high-voltage cable 1, with a central conductor 2, consisting of a plurality of strands 2a. The conductor 2 is surrounded by a inner semiconductive layer 3, of essentially uniform thickness, but this layer 3 has been formed, during the extrusion, into irregularities 3c, 3d, 3e, extending into the insulating layer 4, and exhibits longitudinal scores or scratches 3f, 3g. The magnitude of the defects, in this figure as well as in the previous ones, is greatly exaggerated to clearly show possible deviations from the desired appearance.

The corresponding defects may, of course, occur in the interface between the insulating layer 4 and the outer semiconductive layer 5 although this is not shown in the figures.

Figure 5 shows the cross section of a high-voltage cable 1 in a measuring box 18 filled with a contact fluid (liquid) 19. An array of probes 21, 22, 23, 24 etc, arranged in one or more layers 201 and annularly placed symmetrically around the cable 1, is arranged in the measuring box 18. The shown layer 201 comprises 32 probes 21, 22, 23, 24 etc., four of which 21, 22, 23, 24 being shown connected to a superordinate control unit 20. All the probes in the shown layer 201, as well as in any additional layers (not

shown), cooperate with the superordinate control unit 20 although only a few connections are shown in Figure 5 in order not to complicate the picture unnecessarily.

The high-voltage cable 1 is inserted into and withdrawn from the measuring box 18 through tightly sealing entries (not shown) in the ends of the measuring box 18. By concurrent synchronized activation of a plurality of probes, in a phased array, the measurements may be focussed on the desired positions in the cable, radially (in depth) as well as axially and tangentially. By means of a marking member (not shown), those sections of the high-voltage cable 1, which do not fulfil the quality requirements made on the topography for the interface between an inner semiconductive layer 3 and an insulating layer 4 of crosslinked polyethylene, are marked with a colour.

CLAIMS

1. A method, in a high-voltage cable comprising a conductor, an inner semiconductive layer and an insulating layer, of measuring the topography in the interface between the inner semiconductive layer and the insulating layer, **characterized** by

using ultrasound with a frequency of between 0.1 MHz and 20 MHz, preferably of between 0.5 MHz and 5 MHz,

using a plurality of probes arranged in a fixed array, spatially fixed at the outside of the cable, to emit ultrasound in the form of pulses and to receive (detect) reflected sound (echo), and

activating the probes systematically, one at a time, or a few at a time, such that the pulses are emitted from the probes cyclically with a time lag between the pulses, whereas reflected sound is detected in a plurality of, or in all of, the probes.

2. A method according to claim 1, in a high-voltage cable with an outer diameter of between 10 mm and 100 mm, comprising an insulating layer of crosslinked polyethylene (PEX, XLPE), of measuring the topography in the interface between the inner semiconductive layer and the insulating layer.

3. A method according to claim 1, in a high-voltage cable comprising a conductor, an inner semiconductive layer, an insulating layer and an outer semiconductive layer, of measuring the topography in the interface between the outer semiconductive layer and the insulating layer.

4. A method according to claim 3, in a high-voltage cable with an outer diameter of between 10 mm and 100 mm, comprising an insulating layer of crosslinked polyethylene (PEX, XLPE), of measuring the topography in the interface

between the outer semiconductive layer and the insulating layer.

5. A method according to any of the preceding claims, **characterized** in that the ultrasound is focussed on the respective interface between semiconductive layers and insulating layers.

6. A method according to any of the preceding claims, **characterized** in that the detected ultrasonic signal is amplified selectively such that signals from the respective interface are amplified more than the other signals from intermediate or outside disturbance sources..

7. A method according to any of the preceding claims, **characterized** in that, from the detected signals, the radial distance s between the interfaces of the outer and inner semiconductors, towards the insulating layer, is calculated.

8. A method according to any of the preceding claims, **characterized** in that the gradient of s is calculated, at varying space coordinates along one of the interfaces or at a constant radius in a cylindrical coordinate system, the z-axis of which essentially coincides with the symmetry axis of the high-voltage cable.

9. A method according to any of the preceding claims, **characterized** in that, when the value of the gradient of s exceeds a predetermined limit value, an alarm signal is sent and/or the cable is marked with a colour.

10. A method according to any of the preceding claims, **characterized** in that the frequency of the ultrasound is adapted to the outer diameter of the cable.

11. A method according to any of the preceding claims, **characterized** in that the frequency of the ultrasound is adapted to the diameter of the conductor.

12. A method according to any of the preceding claims, **characterized** in that the frequency of the ultrasound is adapted to the thickness of the inner semiconductive layer.

13. Use of a method according to any of the preceding claims for essentially continuous monitoring of cable manufacture.

14. Use of a method according to any of the preceding claims for laboratory analysis of cables.

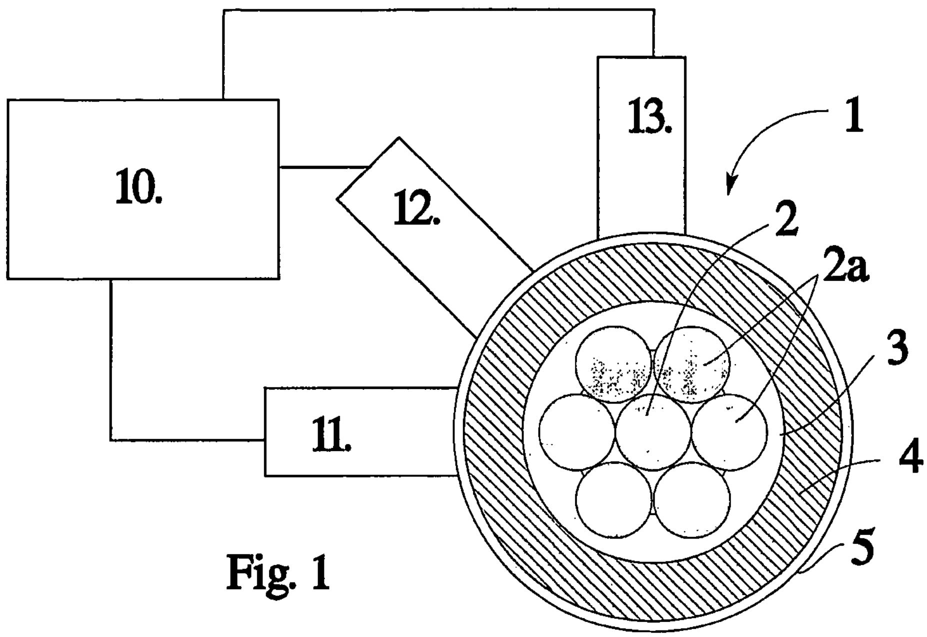

Fig. 1

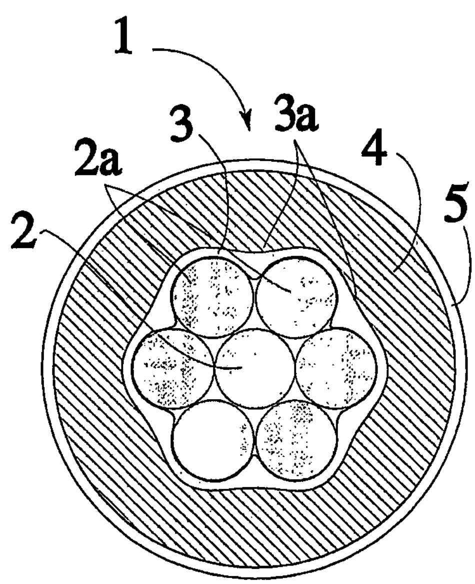

Fig. 2

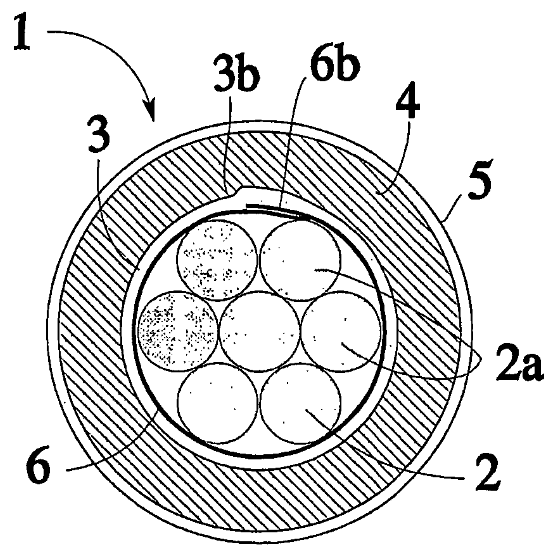

Fig. 3

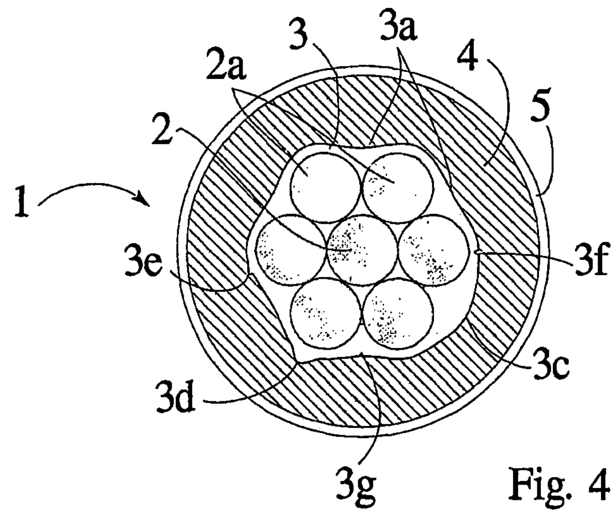

Fig. 4

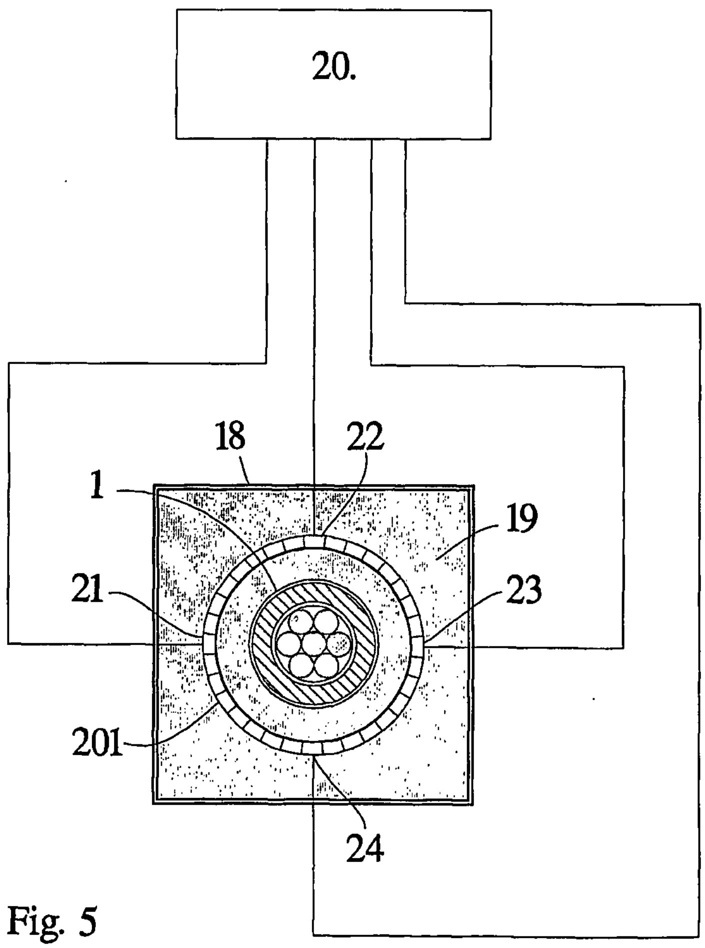

Fig. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 01/01007

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: G01N 29/00, G01N 29/04, G01N 29/06 // G01B 17/08, G01S 15/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: G01N, G01B, G01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI, EPODOC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
8 August 2001	09-08-2001

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INTERNATIONAL SEARCH REPORT

International application No.
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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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